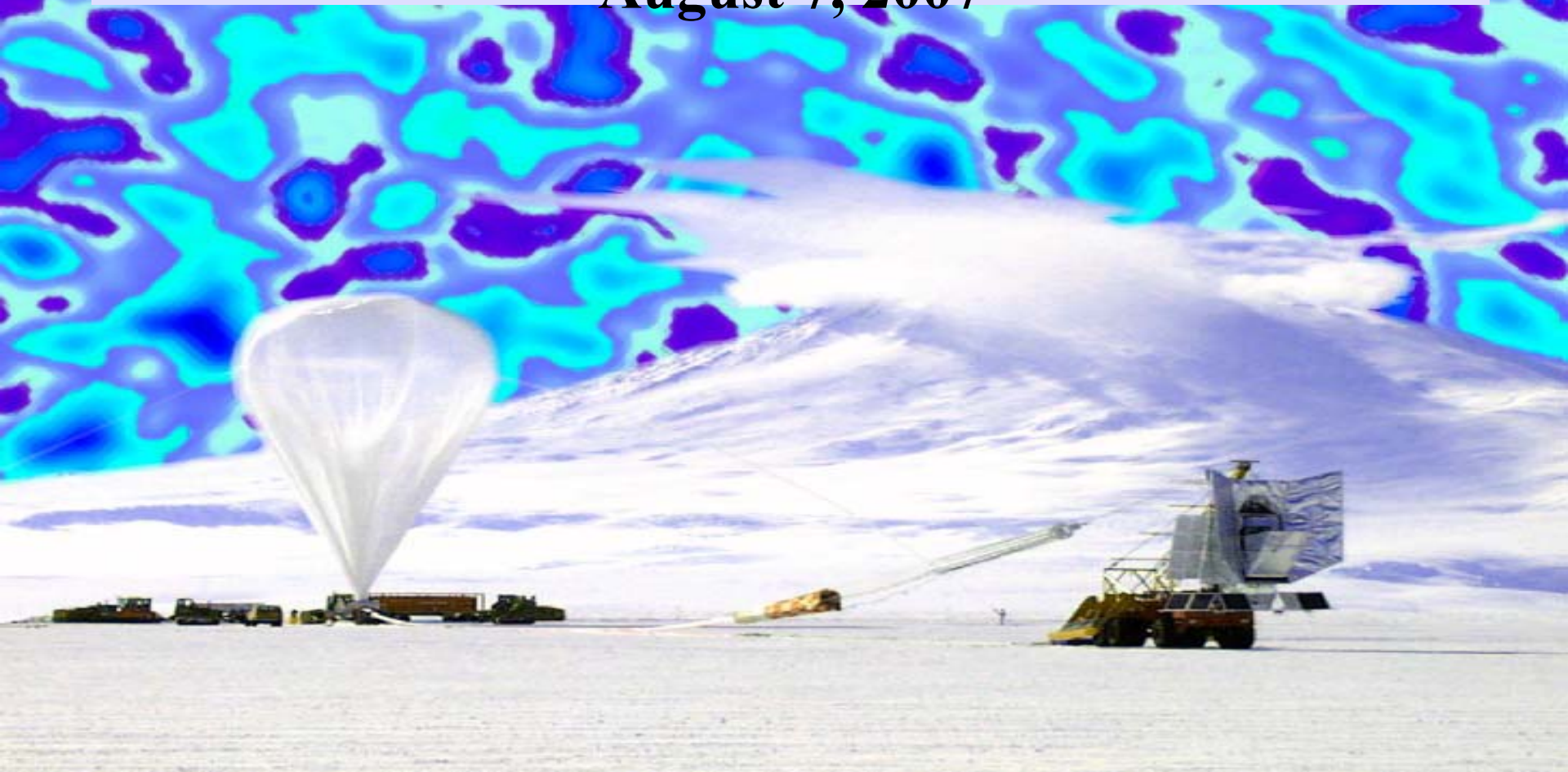


# CMB Science from Balloons

Andrew Lange  
Caltech

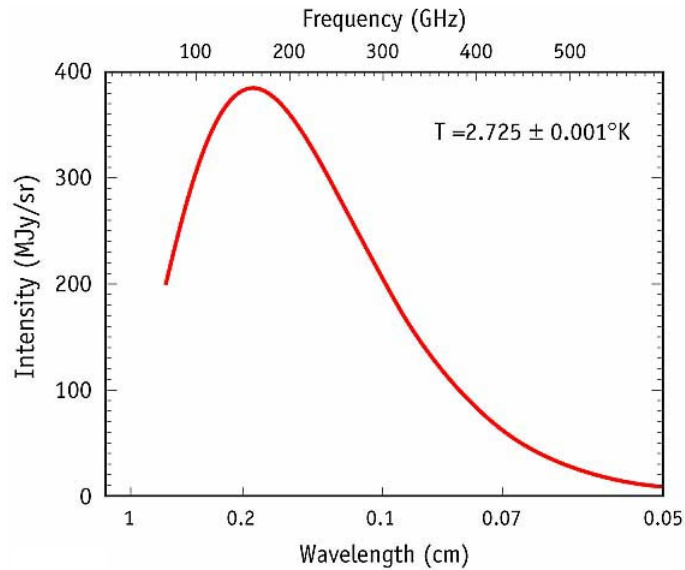
August 7, 2007



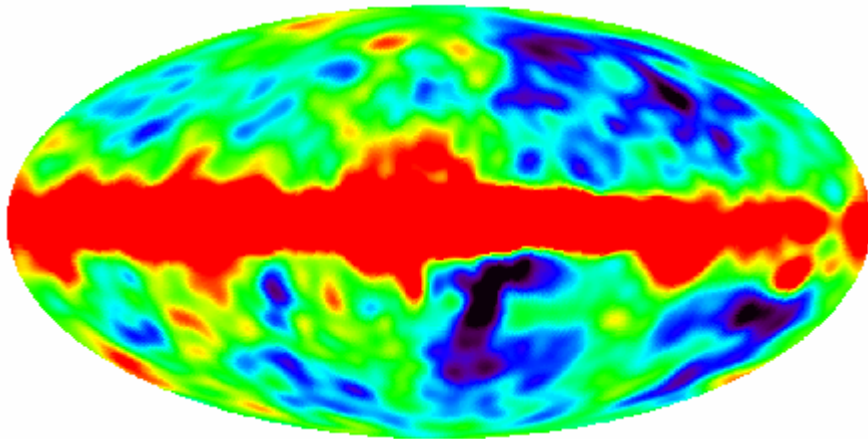
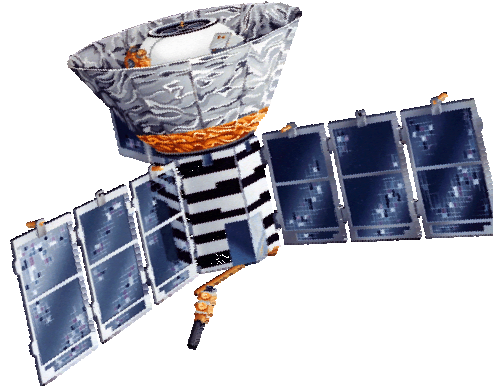
# Main points

- Balloons preceded each of COBE, WMAP & Planck
- Why balloons? (can see CMB from ground)
  - Lower backgrounds ( ~ orbital)
  - Broader frequency coverage available
  - Most important for largest angular scales
- The Next Step: “seeing” Inflation in CMB polarization
- Needs:
  - mid-latitude ULDB (> 1.5 ton to > 60kft for > 25 days)
- Payloads: EBEX / PAPPa / SPIDER
  - (berkeley / gsfc / jpl detectors)

# Balloon Heritage



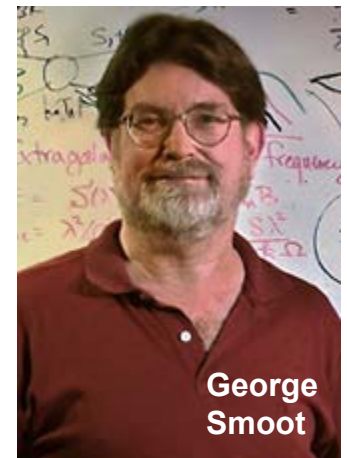
**COBE-FIRAS spectrum of the CMB**



**COBE-DMR anisotropy of the CMB**



**2006 Nobel Prize  
in Physics**

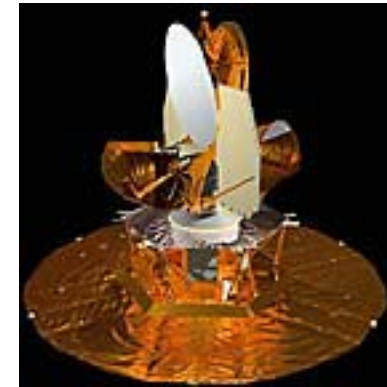
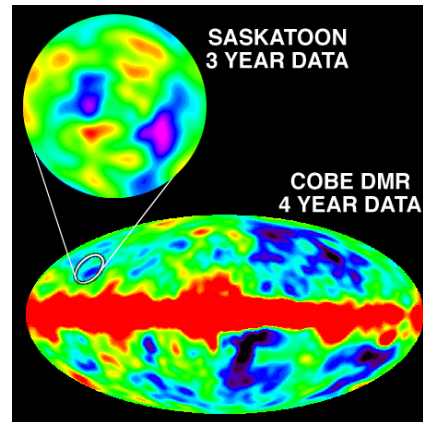
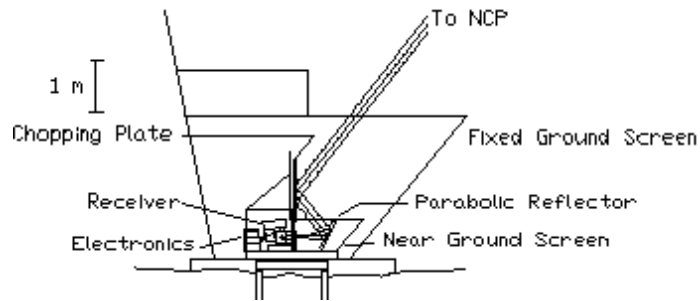


# Ground vs. balloon based experiments

Saskatoon



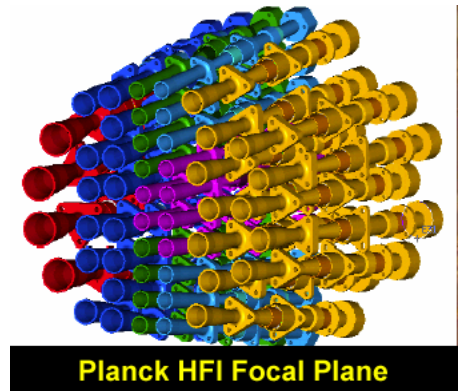
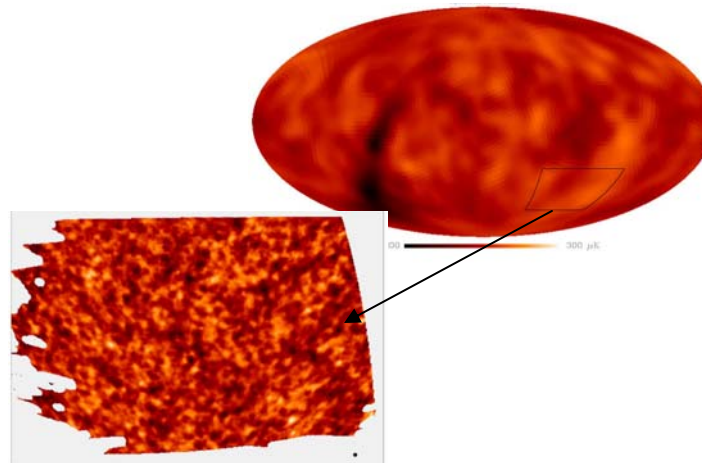
MAP



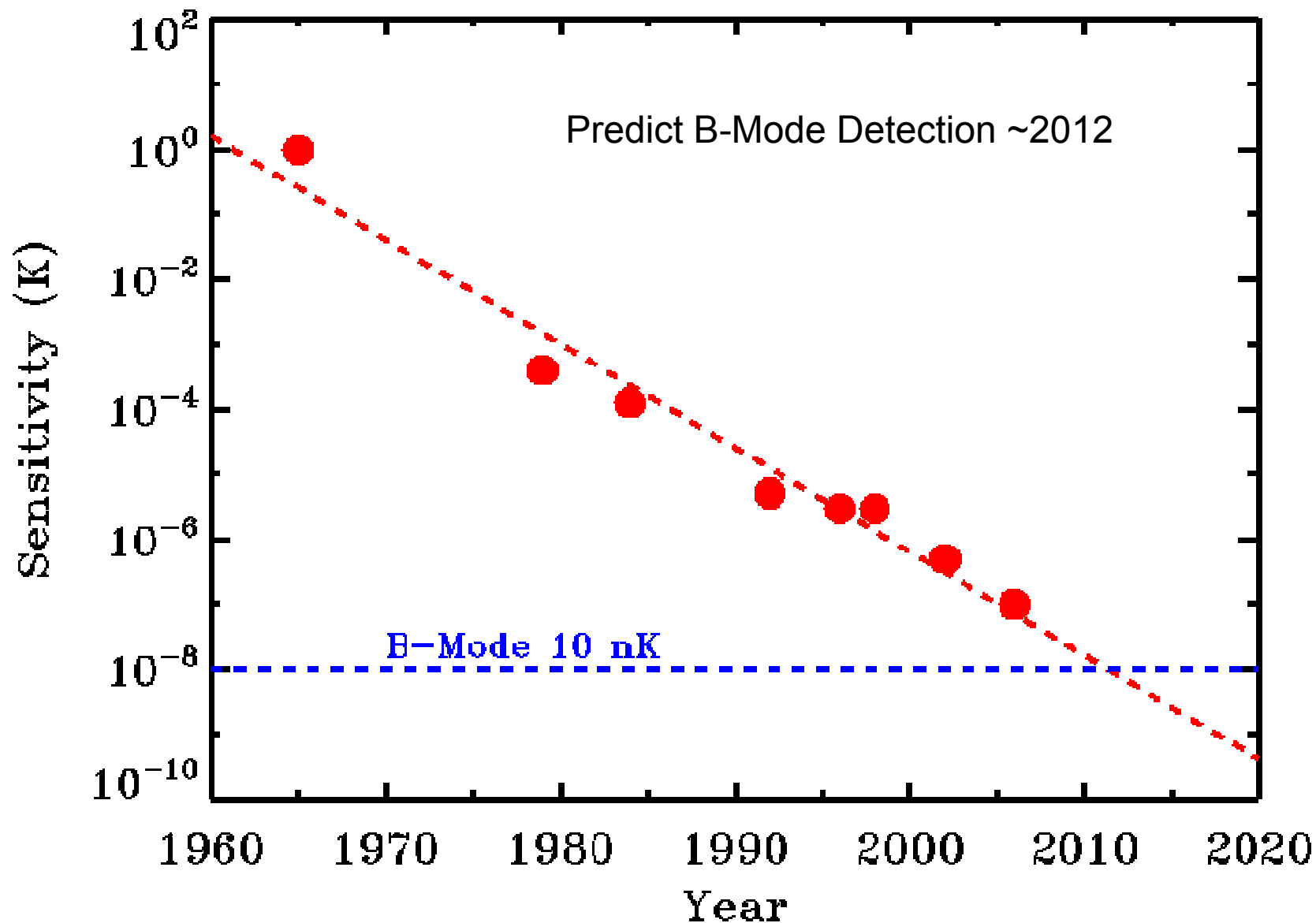
Boomerang



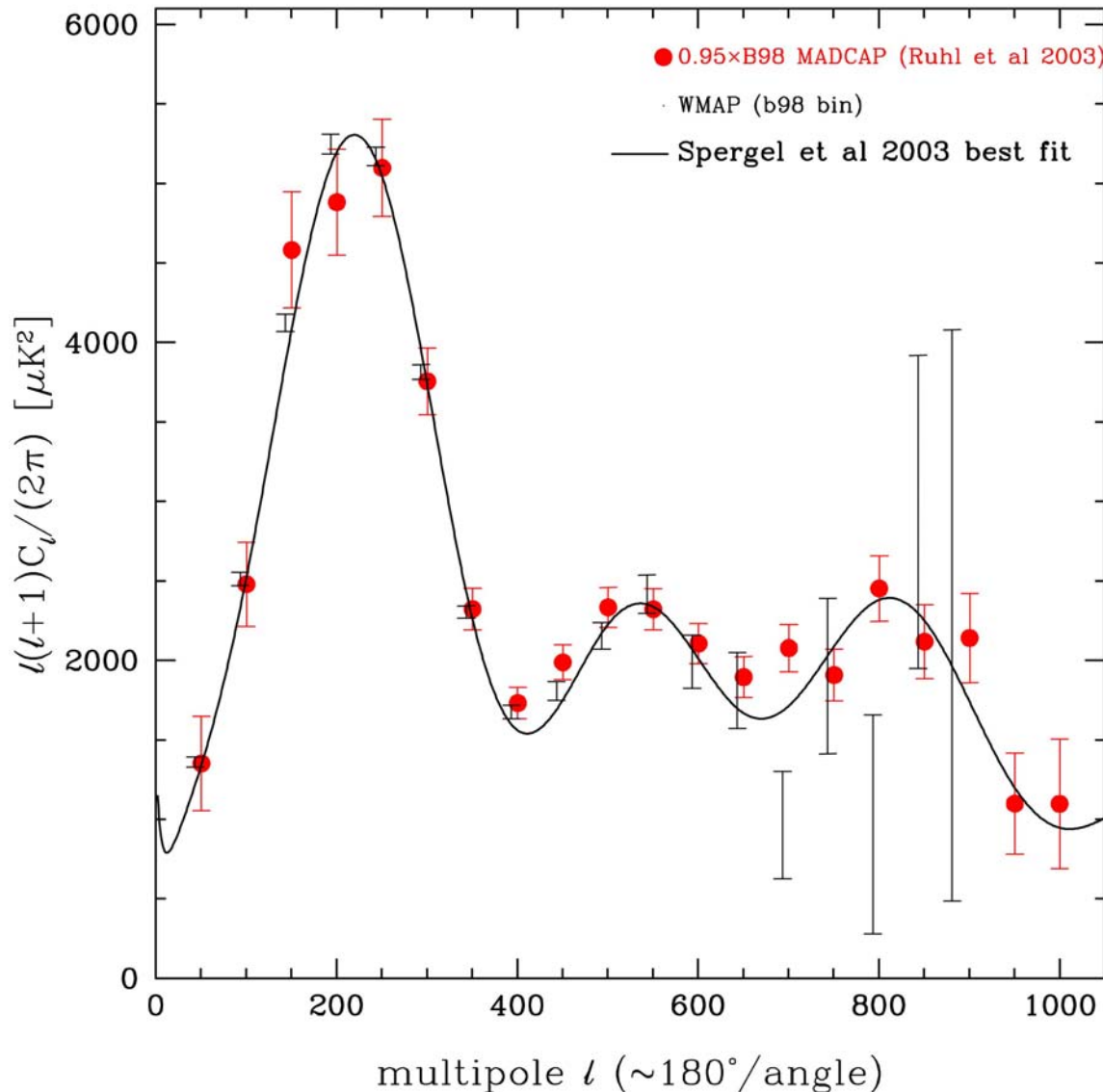
Planck



# CMB Sensitivity vs Time



# Rapid advances in technology make ballooning competitive with orbital missions



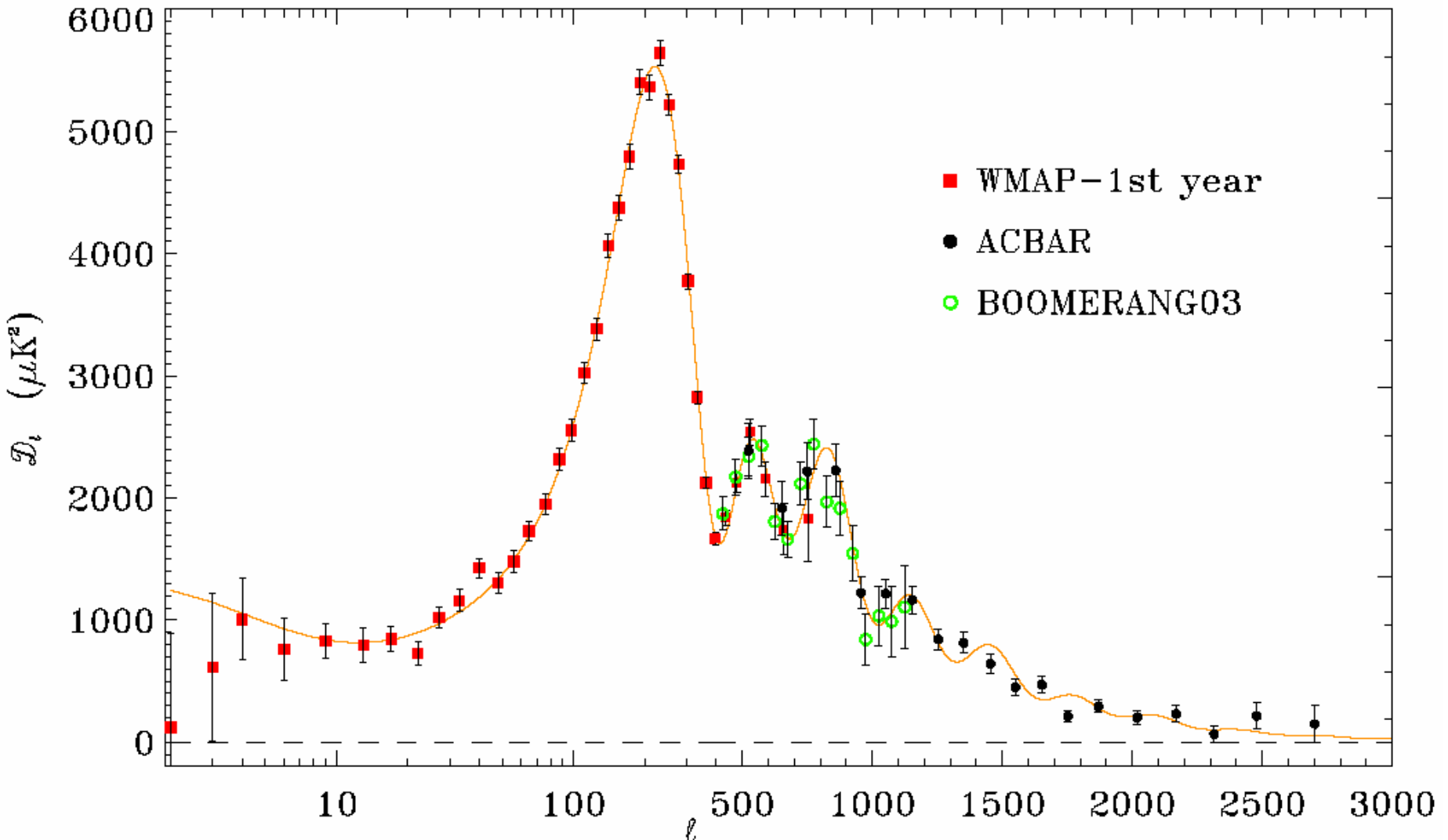
## WMAP

- full-sky
- highly accurate calibration
- smaller errors at low  $\ell$

## BOOMERanG

- higher sensitivity
- higher resolution
- smaller errors at high  $\ell$

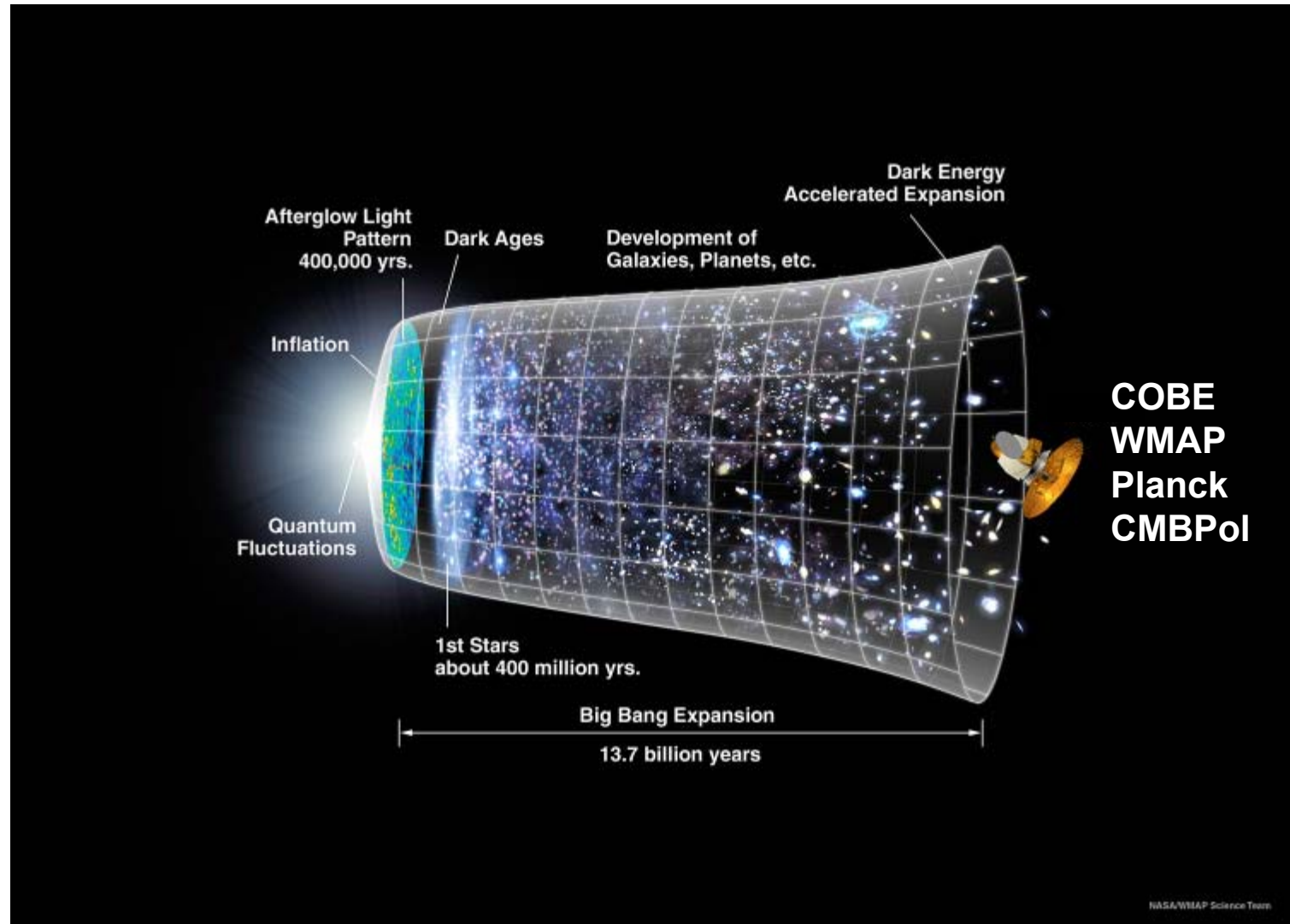
# Predictions of **Inflation** (so far) correct !



# What comes next?

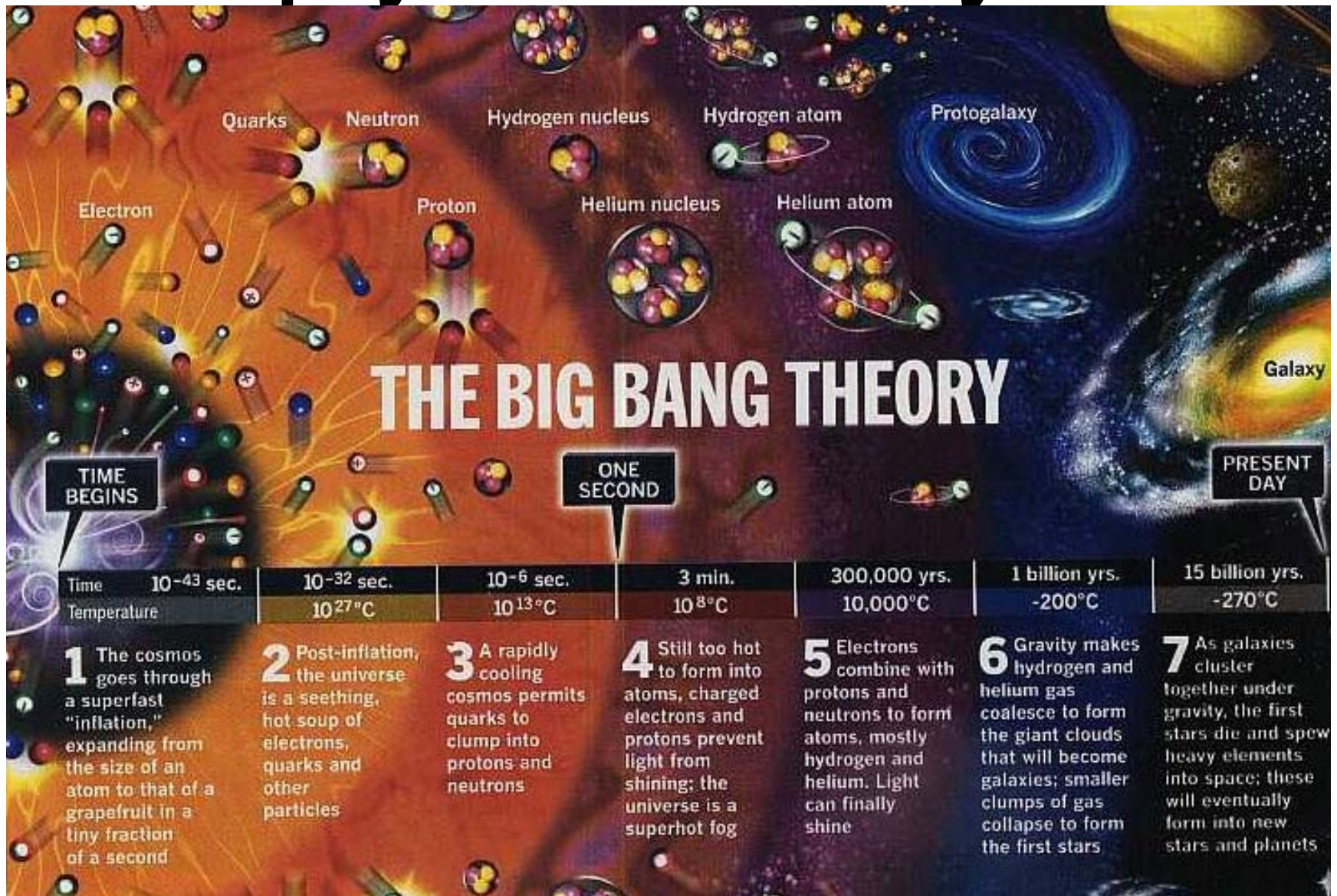


# Probing Inflation with the CMB



The only thing standing between the CMB and inflation is a thin layer of warm plasma.

# The ultimate high energy physics laboratory...



# What Powered the Big Bang?

Gravitational Waves can Escape from  
Earliest Moments of the Big Bang

**Inflation**  
(Big Bang plus  
 $10^{-35}$  seconds?)

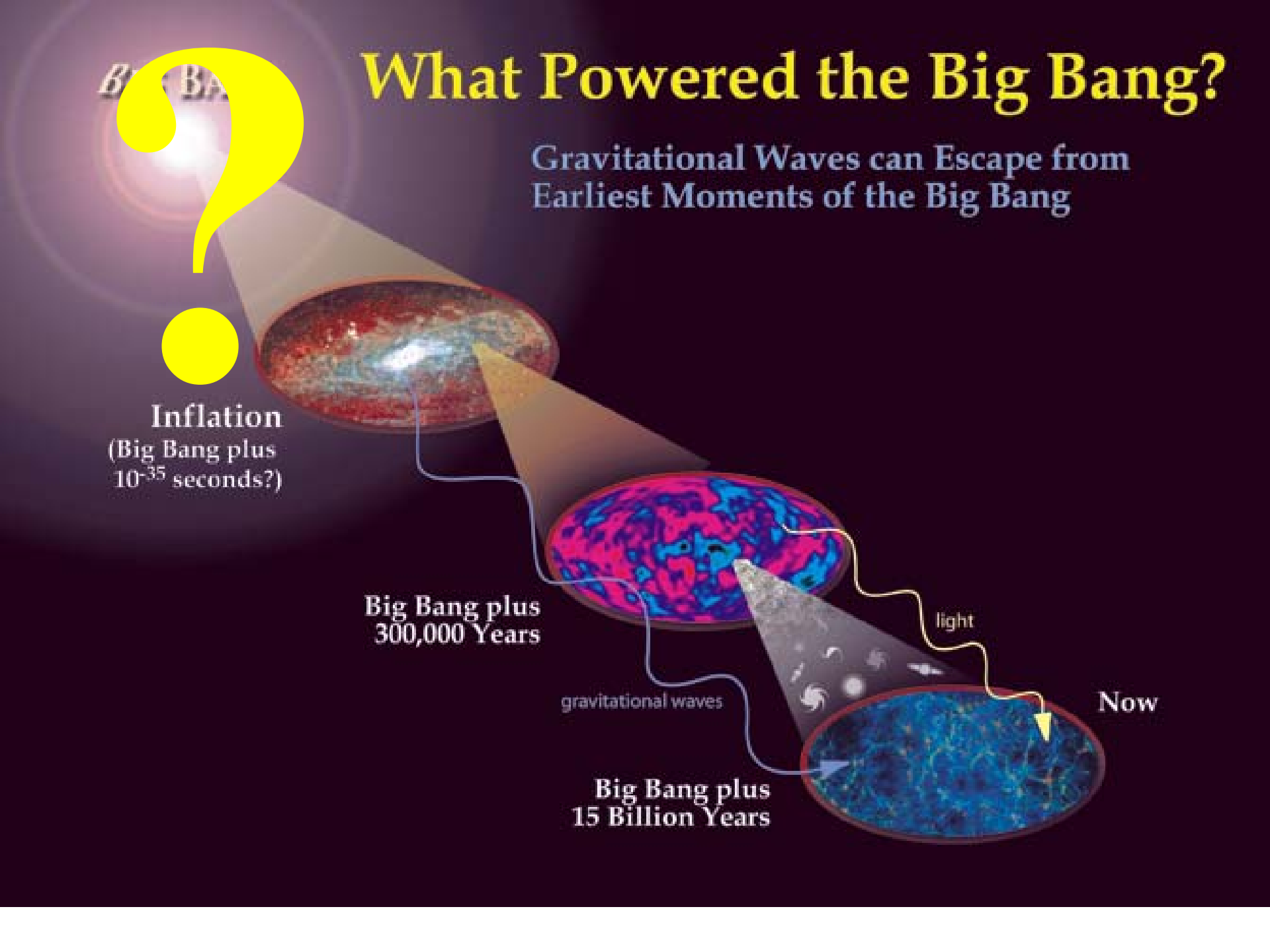
Big Bang plus  
300,000 Years

gravitational waves

Big Bang plus  
15 Billion Years

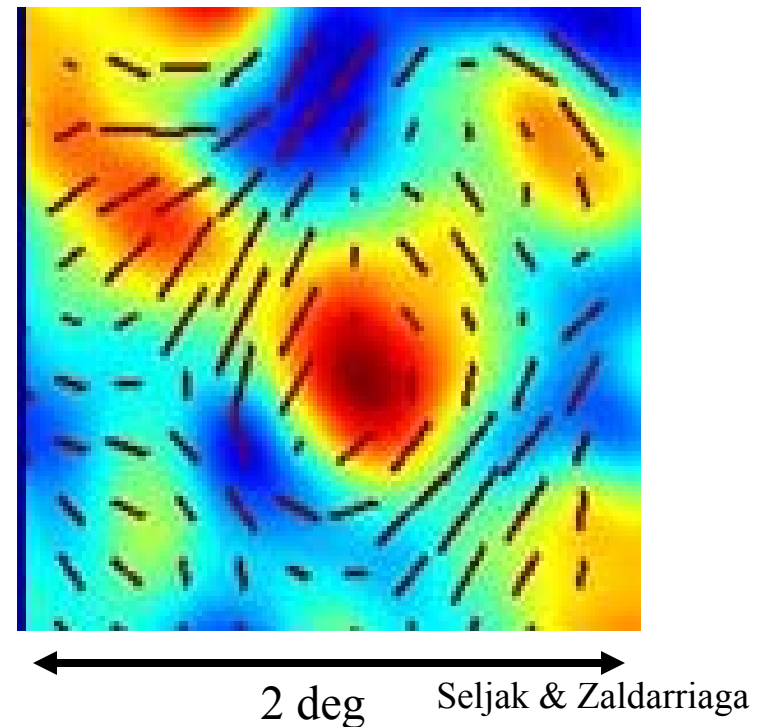
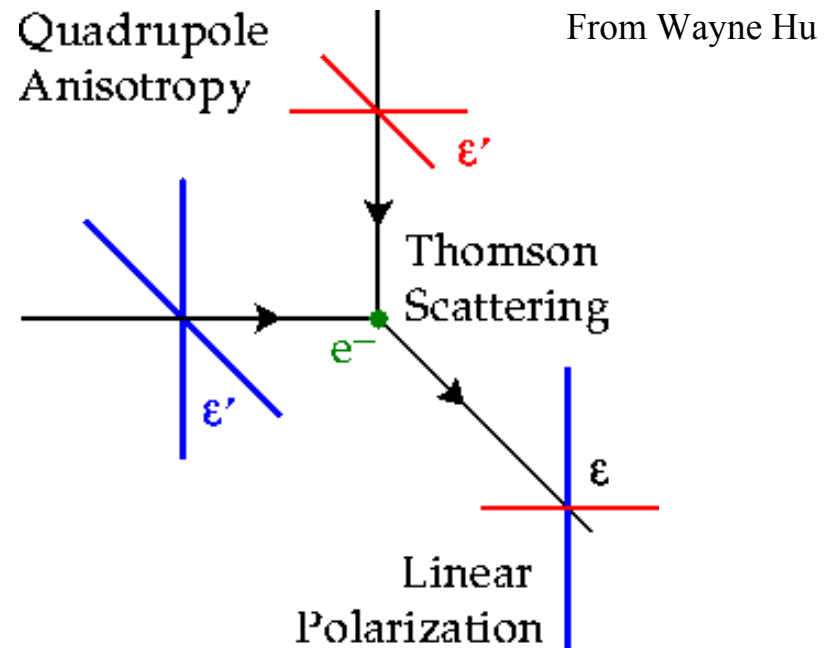
light

Now



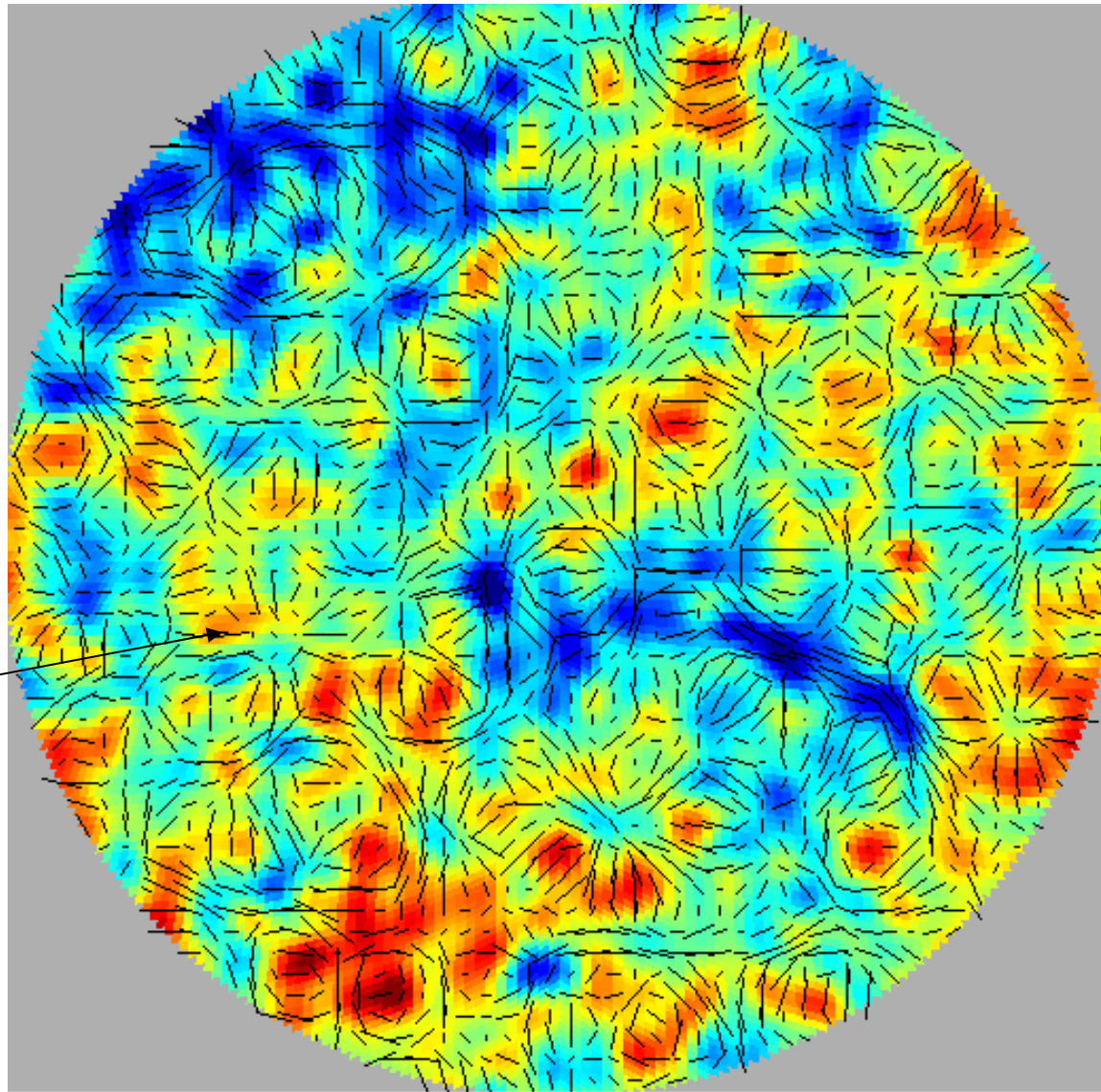
# CMB Polarization

- ❖ Polarization of the CMB is produced by Thomson scattering of a quadrupolar radiation pattern.
- ❖ A component of the polarization is correlated with the temperature anisotropy.
- ❖ Whenever there are free electrons, the CMB is polarized.



# No Gravitational Waves

Few % polarized,  
just like light  
reflected off of  
ice...

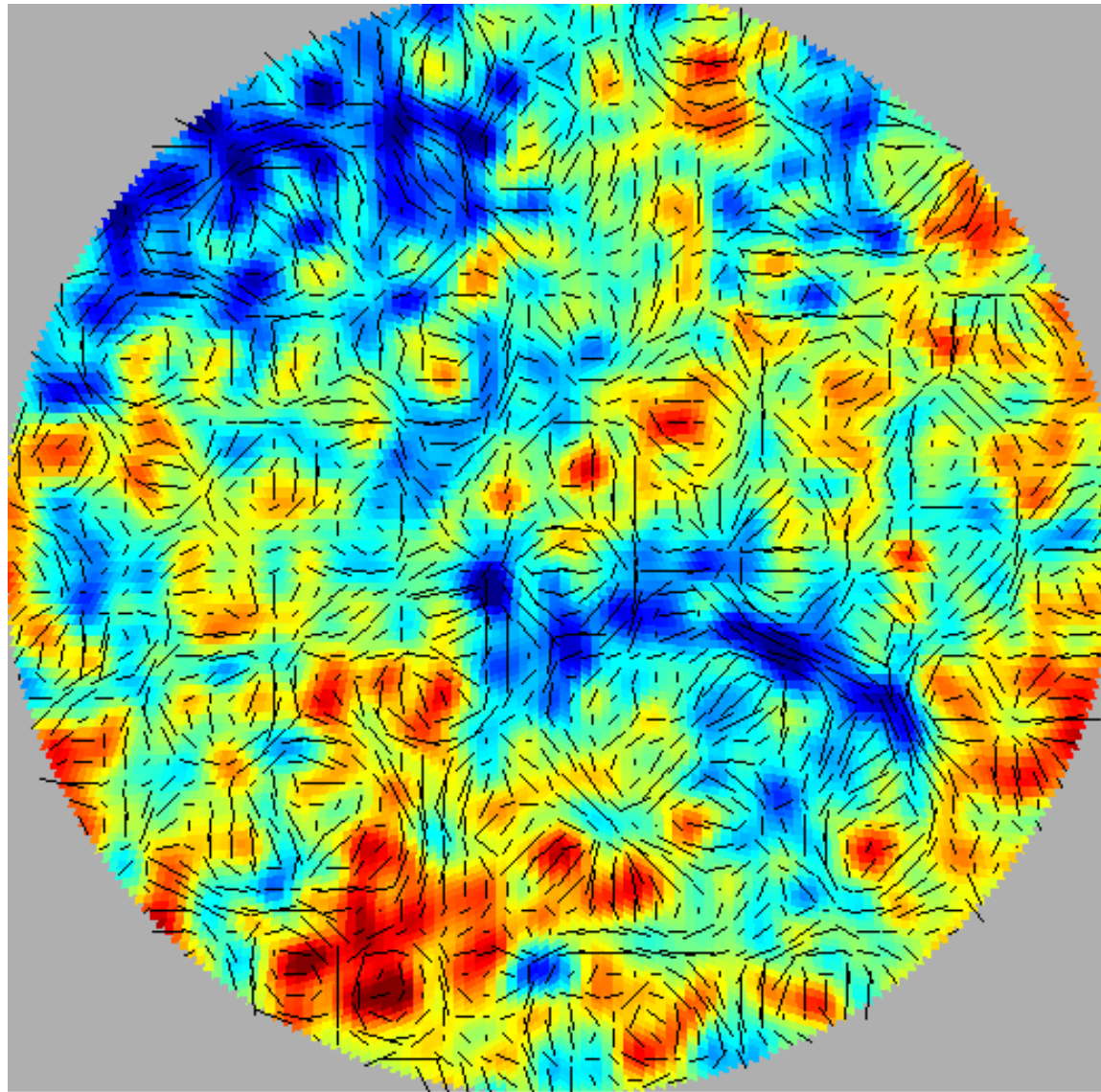


3.47  $\mu\text{K}$

-200 200  $\mu\text{K}$

Eric Hivon

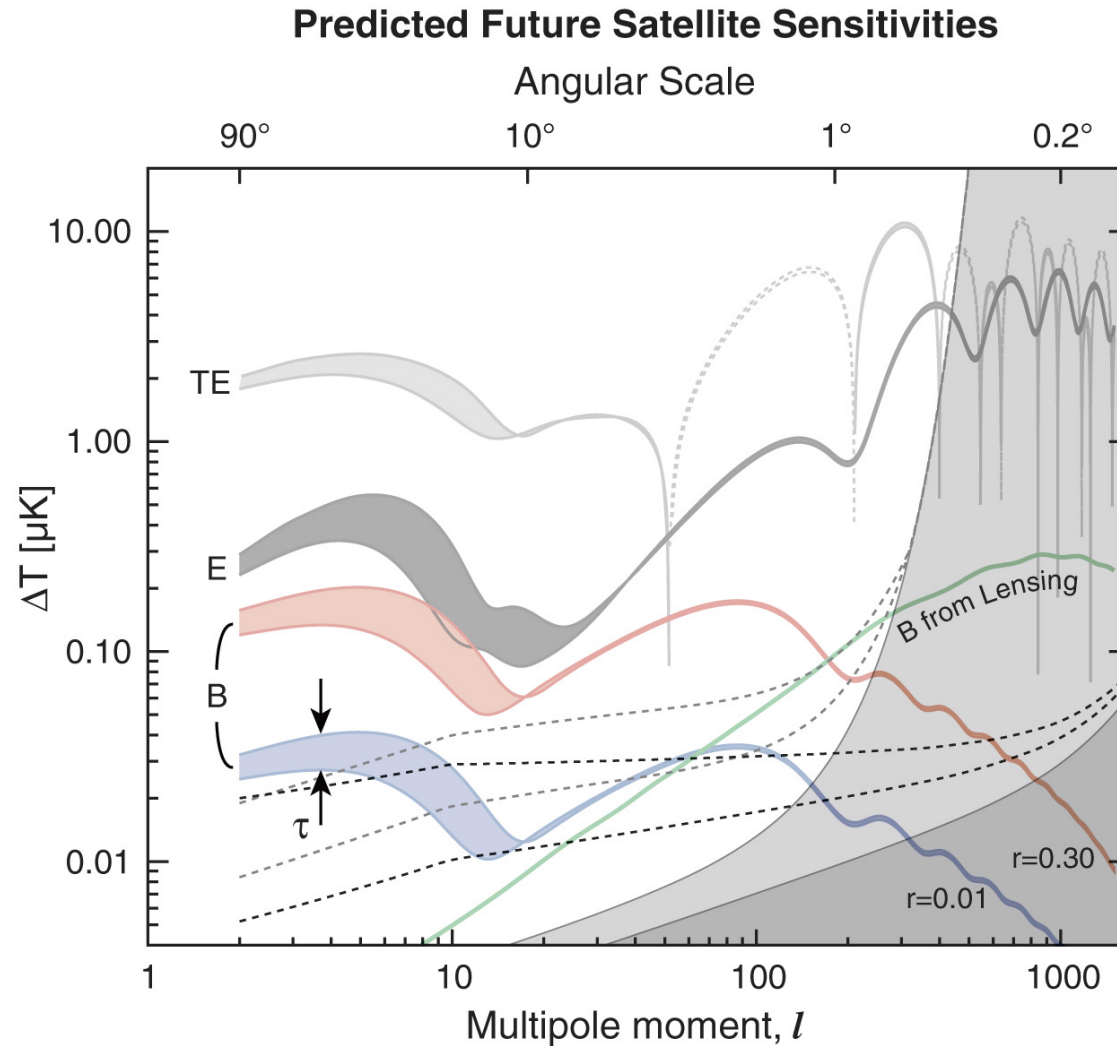
# Gravitational Waves



3.75  $\mu\text{K}$       -200      200  $\mu\text{K}$

Eric Hivon

# What does the signature look like?

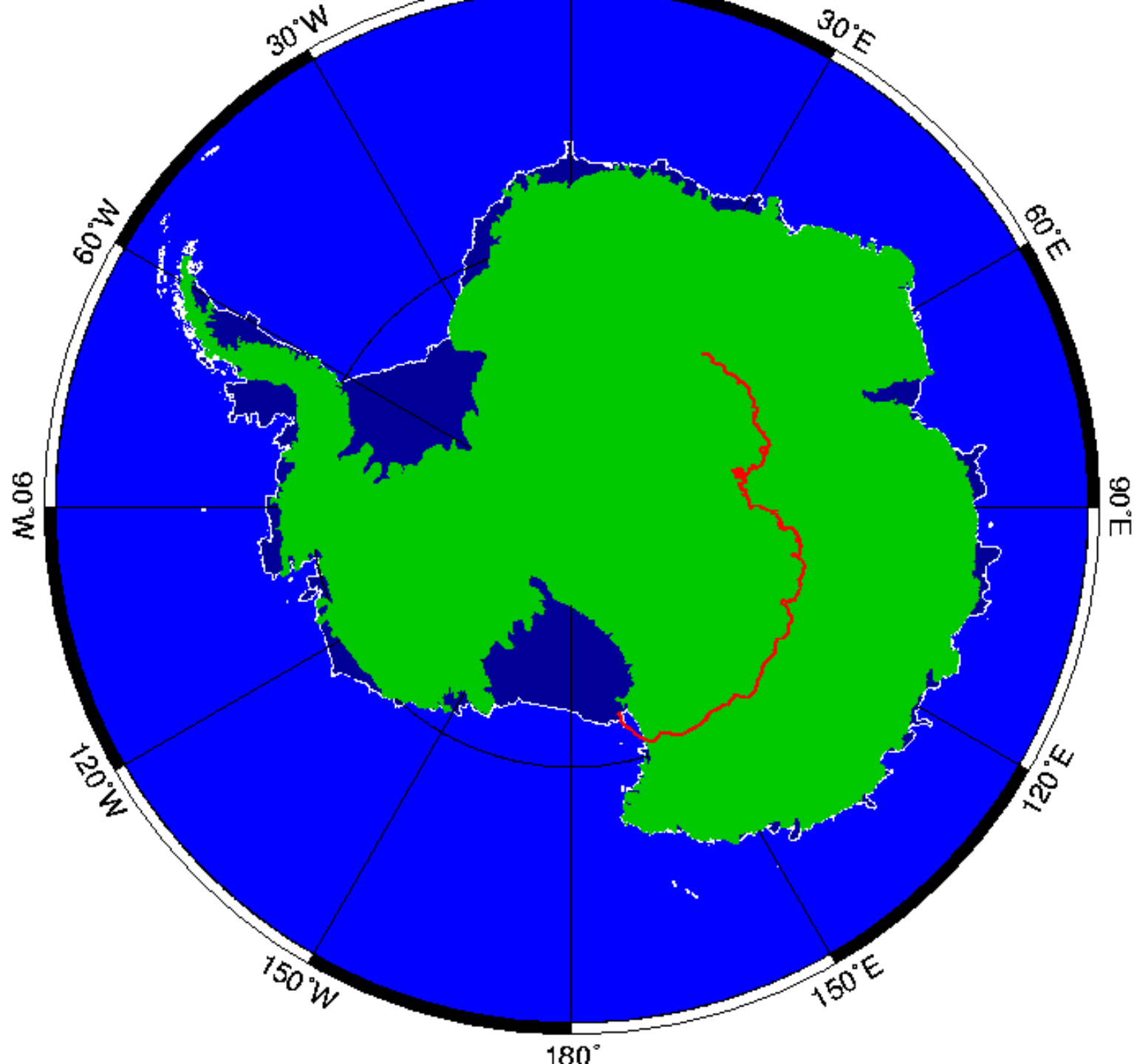


Weiss Committee Report (2005):

google: “CMB Task Force Final Report”

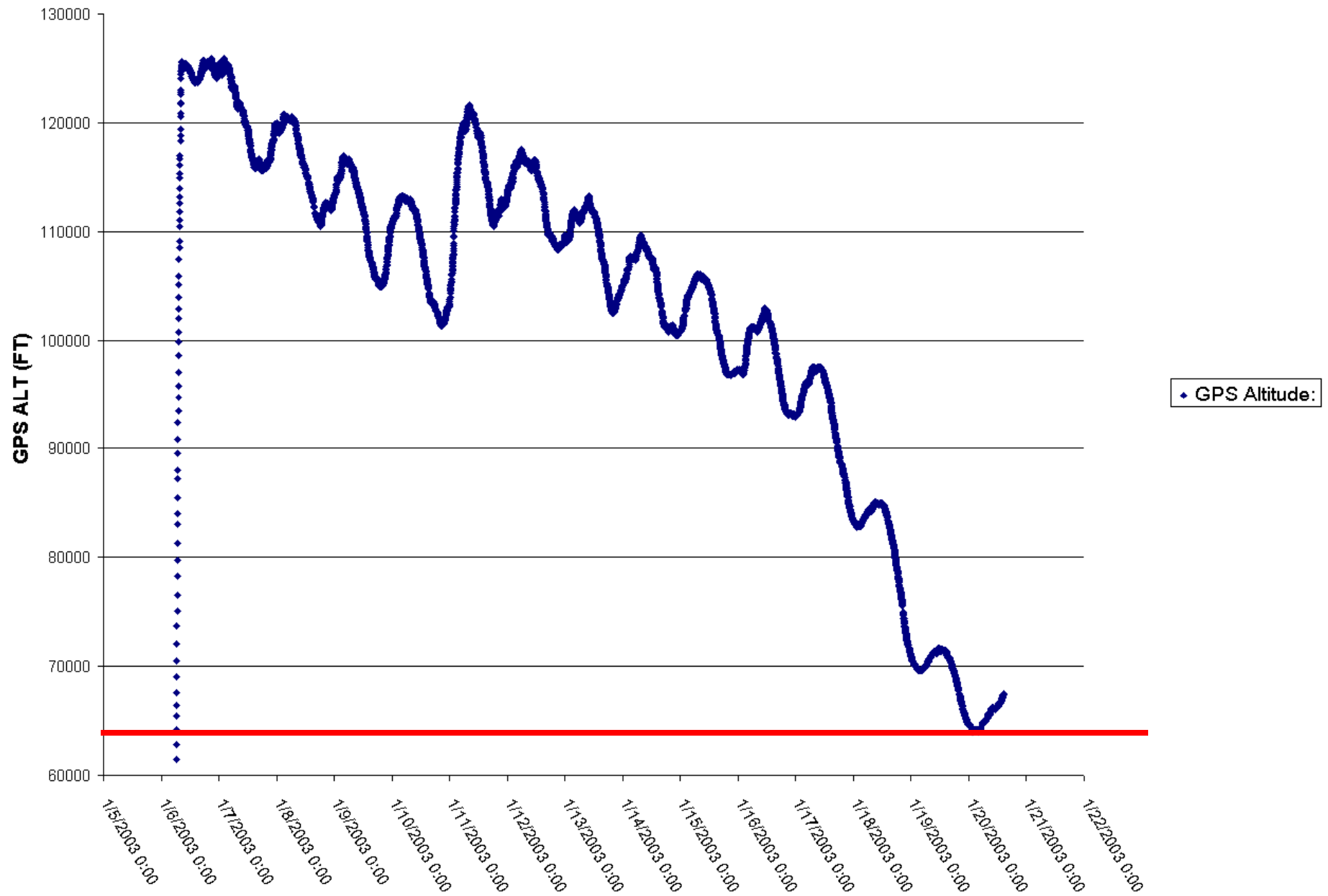
# 6 polarized detectors flew in 2003...



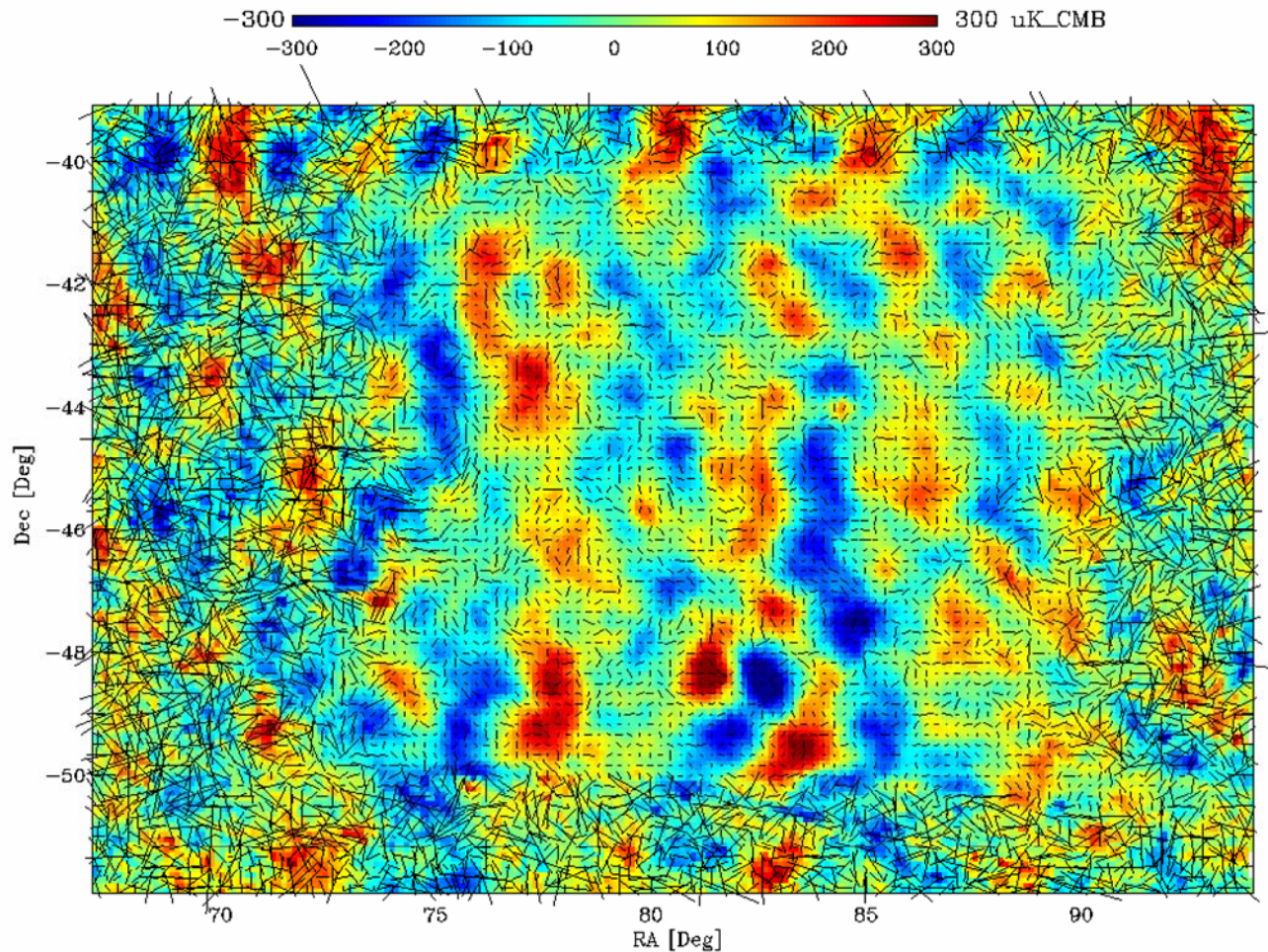


# GPS Altitude - BOOMERANG (516N)

Jan 5, 2003 - Jan 20, 2003

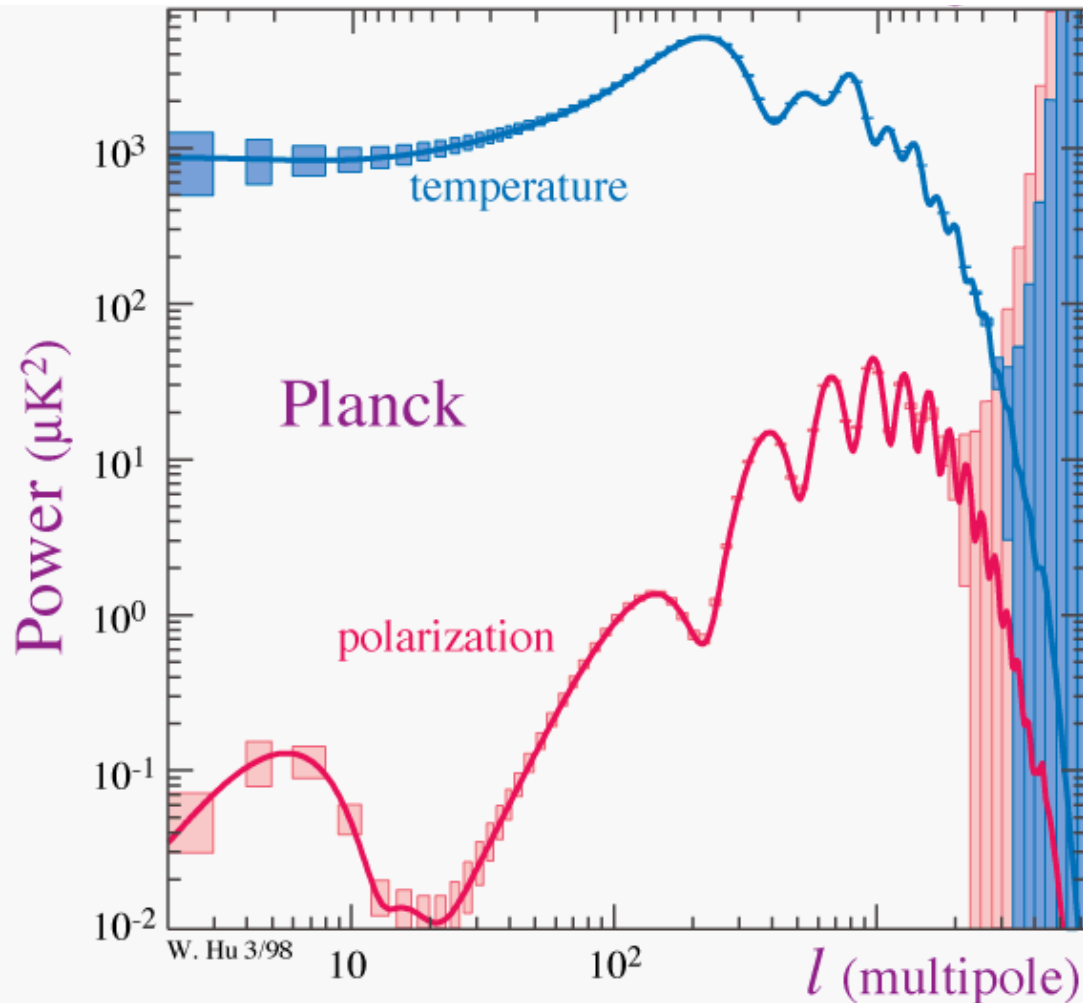


Signals are **very** faint but we have already been able to detect polarization:

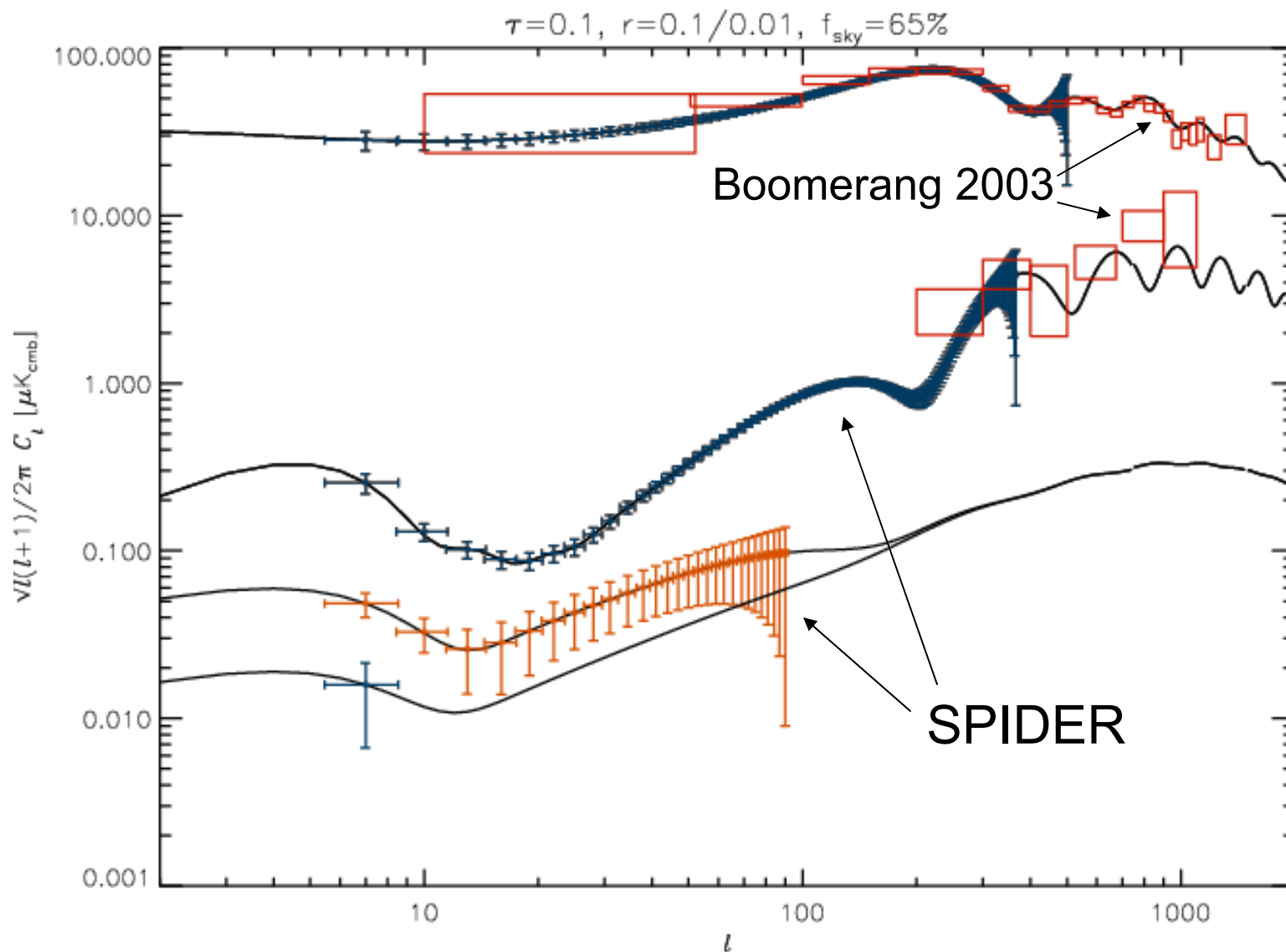


**Boomerang (2003), also DASI (2001), CBI (2002)**

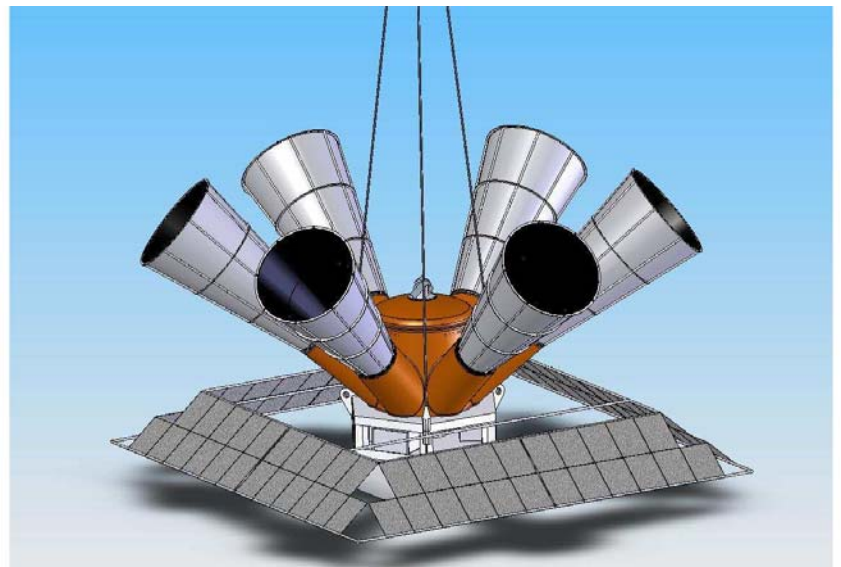
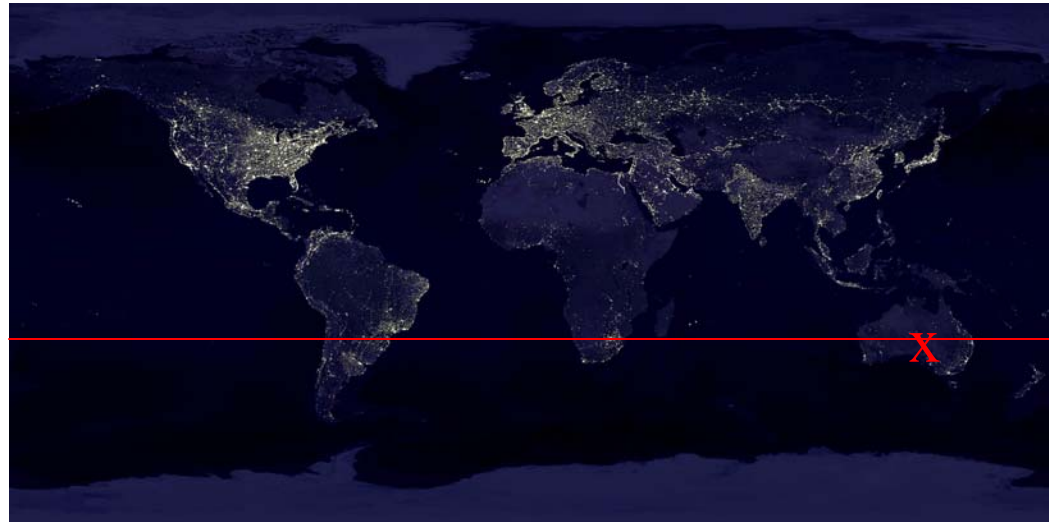
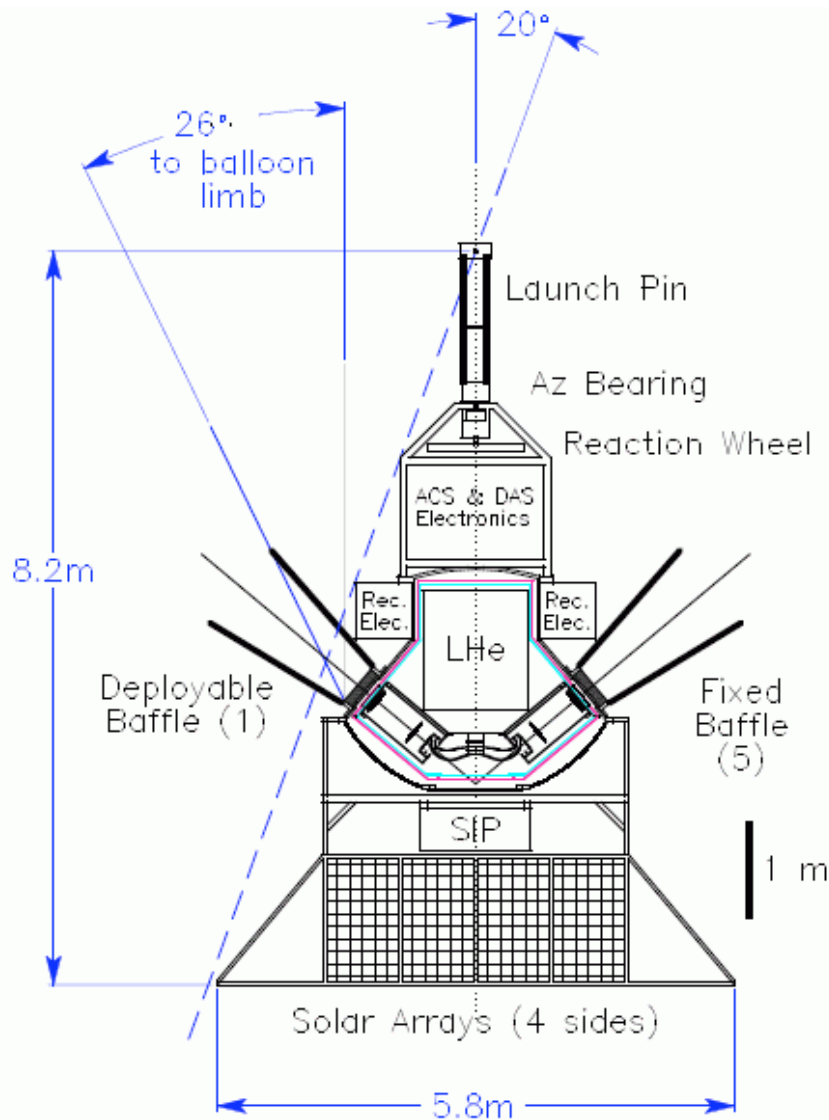
# Ballooning enabled polarization capability of Planck



# Recent past and near future...

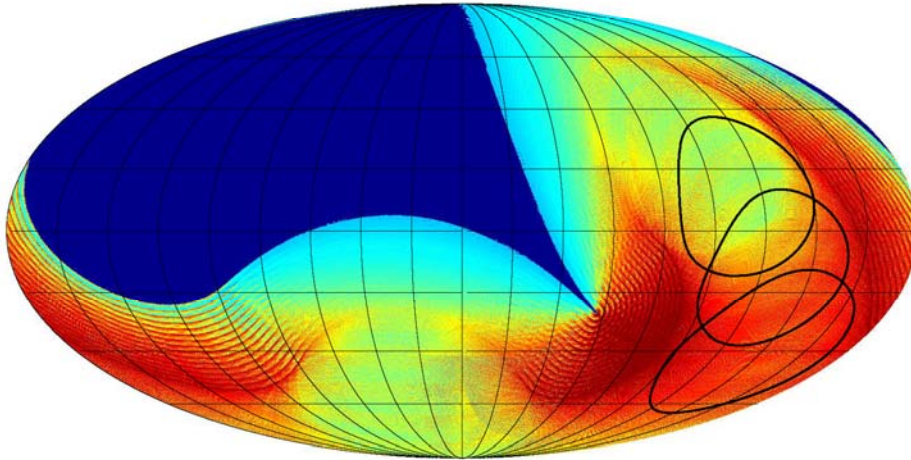


# SPIDER: Six telescopes, ~ 3,000 detectors.



# Spider sky coverage

Daily Sky Coverage

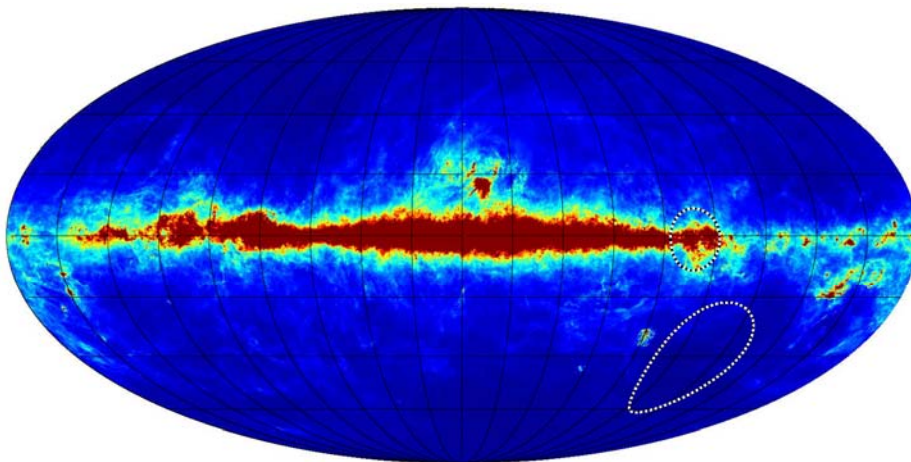


2 day turn-around flight in  
fall 2009

LDB ~ 25 day “racoon”  
flight in late 2010

(would prefer ULDB!!)

Galactic Dust Emission

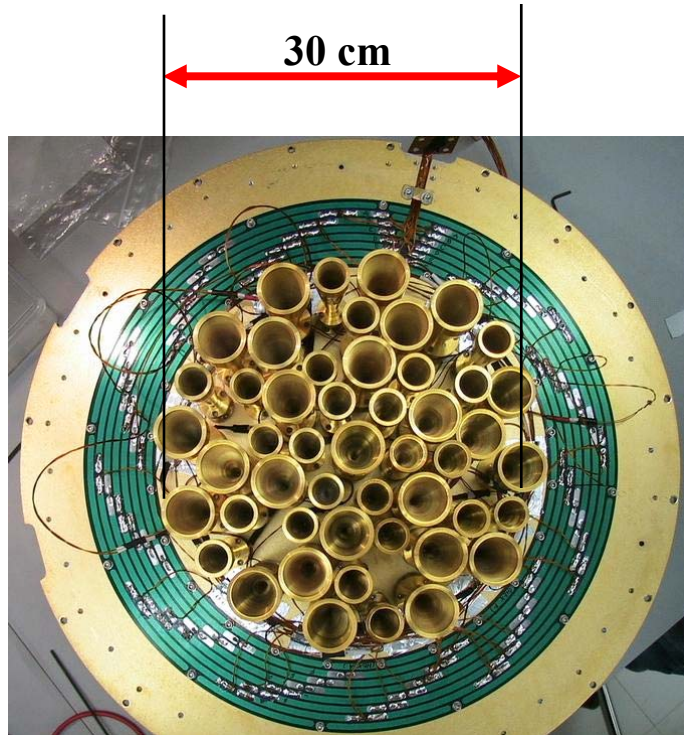


Northern Hemisphere  
flight in 2011-> 2012?

# Bolometric Polarimeters

## *The state-of-the-art:*

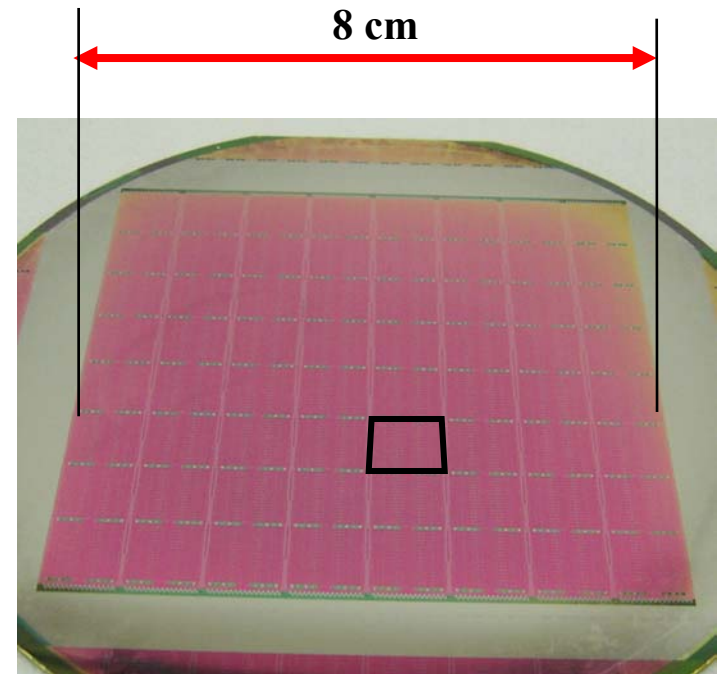
- Co-locating dual-polarization polarimeter
- High optical efficiency, wide band
- Extremely stable
- Nice beam/beam
- Low polarization artifacts
- Discrete elements: feeds, filters, detectors



**BICEP focal plane (98 detectors)**

## *The future:*

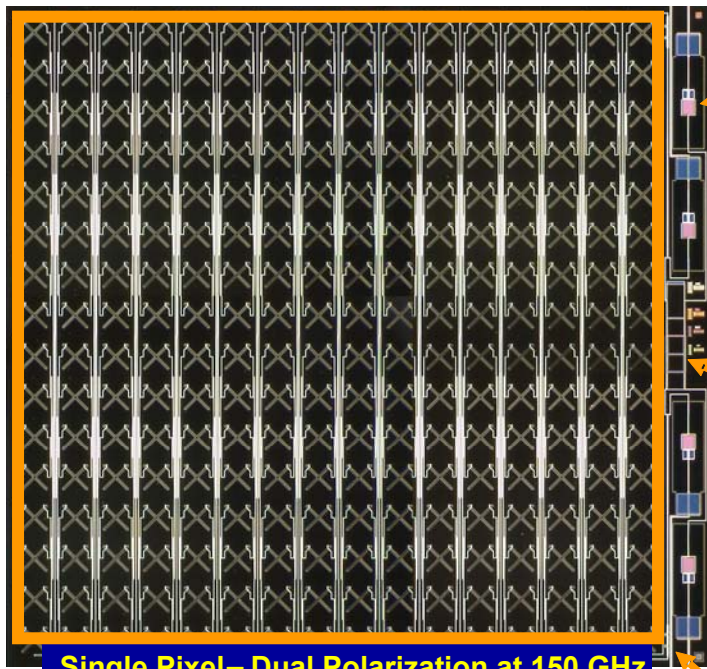
- To integrate all these components on a Si wafer → mass production
- Higher packing density
- TES enables SQUID multiplexed read-out



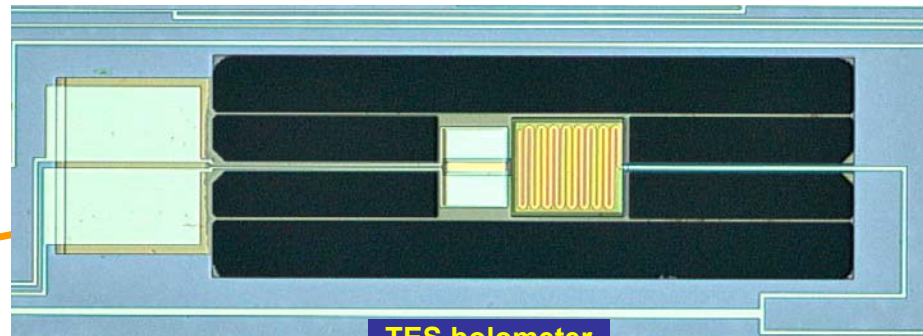
**Antenna-coupled TES array  
(512 Q/U detectors)**

# The components of a “pixel”

Beam synthesizing antennas  
w/ low loss Nb microstrips

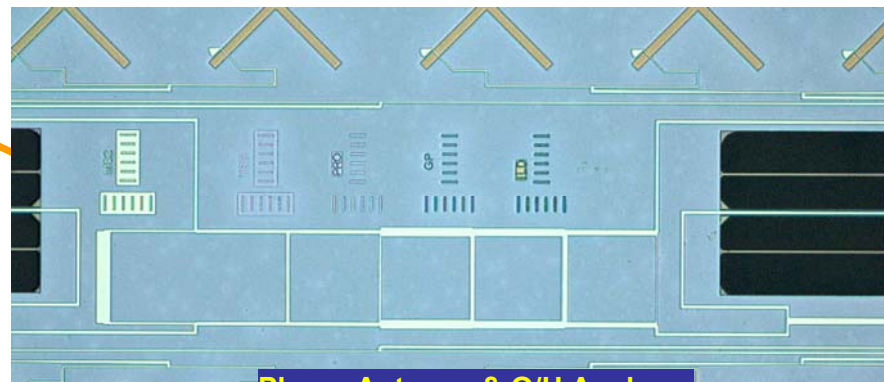


Single Pixel– Dual Polarization at 150 GHz



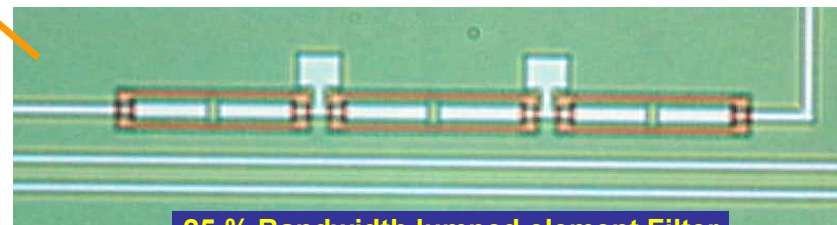
TES bolometer

Superconducting Transition Edge Sensors



Planar Antenna & Q/U Analyzer

Simultaneous Q/U measurements  
can be done with  $180^\circ$  hybrids (pre-detection)



25 % Bandwidth lumped element Filter

## Advantages for CMBPOL

- TES detectors ..... **CMBPOL sensitivities already demonstrated**
- SQUID multiplexing ..... **Large formats  $\geq 10^4$  elements**
- Small active volume ..... **Operates from 30 – 500 GHz**
- Beam collimation ..... **Eliminates discrete feeds**
- Intrinsic filters ..... **No discrete components**

# (some of the) SPIDER team

Caltech/JPL

Case Western

NIST

Toronto

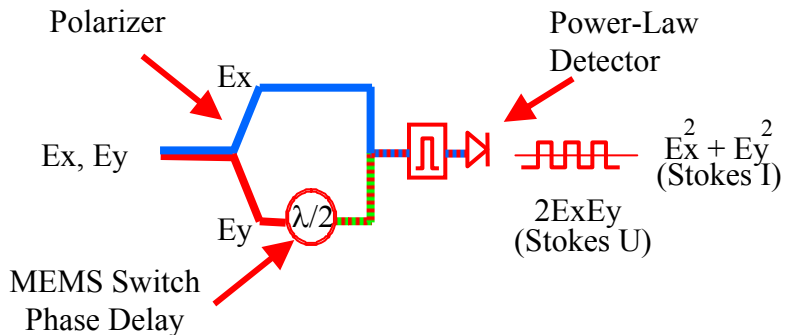
U. of British  
Columbia



# PAPPA: Primordial Anisotropy Polarization Pathfinder Array

(Al Kogut, GSFC)

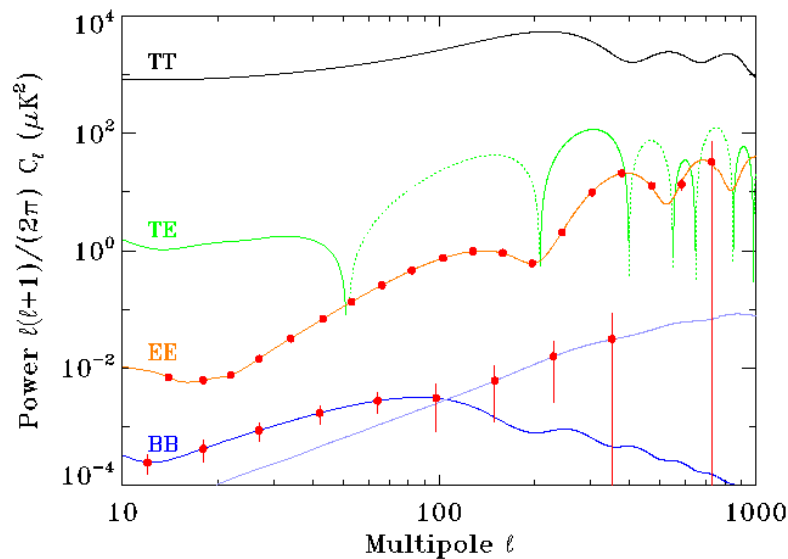
Polarimeter-On-A-Chip



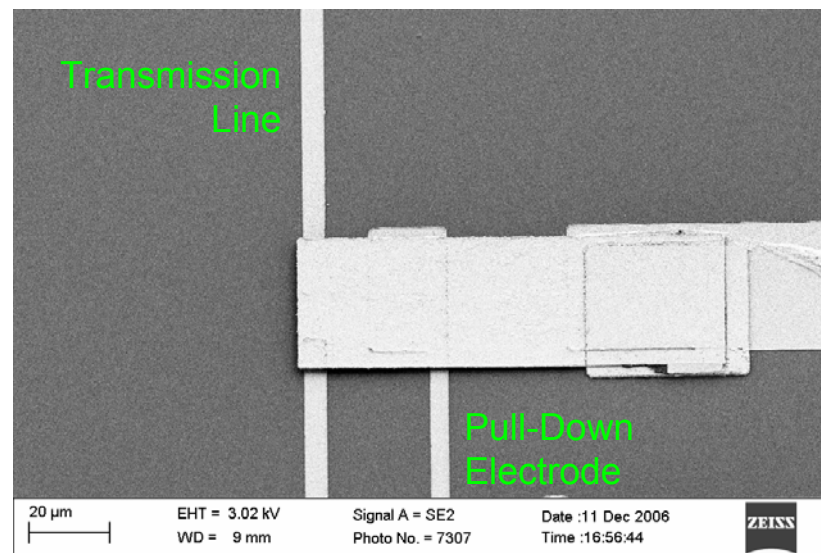
Schematic of PAPPA circuit

- MEMS technology in planar microcircuit
- Rapid (100 Hz) polarization modulation
- No macroscopic moving parts!
- Scalable to kilo-pixel arrays

First flight September 2009



Sensitivity for LDB flight



MEMS Phase Switch

# PAPPA Ballooning Requirements

Large payload, long duration

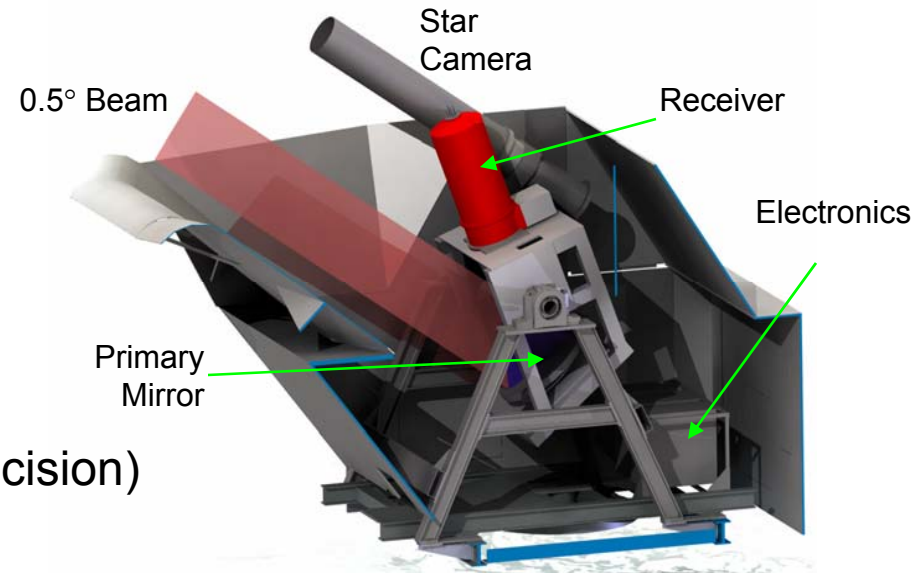
- Payload weight > 1800 pounds
- Flight duration 14 days

Mission Requirements

- Pointed observations (arc-min precision)
- Superfluid LHe dewar
- Altitude > 100 kft

Flight Timeline

- North American flight September 2009
- LDB Antarctic flight January 2011



PAPPA 2009 payload

# EBEX Collaboration (*Shaul Hanany, UM*)

---

Asad Aboobaker, Peter Ade, Francois Aubin, Carlo Baccigalupi,  
Eric Bissonnette, Matt Dobbs, Will Grainger, Shaul Hanany,  
Clayton Hogen-Chin, Sherry Cho, Hannes Hubmayr, Bradley  
Johnson, Terry Jones, Jeff Klein, Andrei Korotkov, Sam Leach,  
Adrian Lee, Lorne Levinson, John Macaluso, Kevin Macdermid,  
Tomotake Matsumura, Xiaofan Meng, Amber Miller, Michael Milligan,  
Enzo Pascale, Dan Polsgrove, Nicolas Ponthieu,  
Britt Reichborn-Kjennerud, Ilan Sagiv, Helmuth Spieler,  
Federico Stivoli, Radek Stompor, Huan Tran, Greg Tucker,  
Jerry Vinokurov, Matias Zaldarriaga, Kyle Zilic

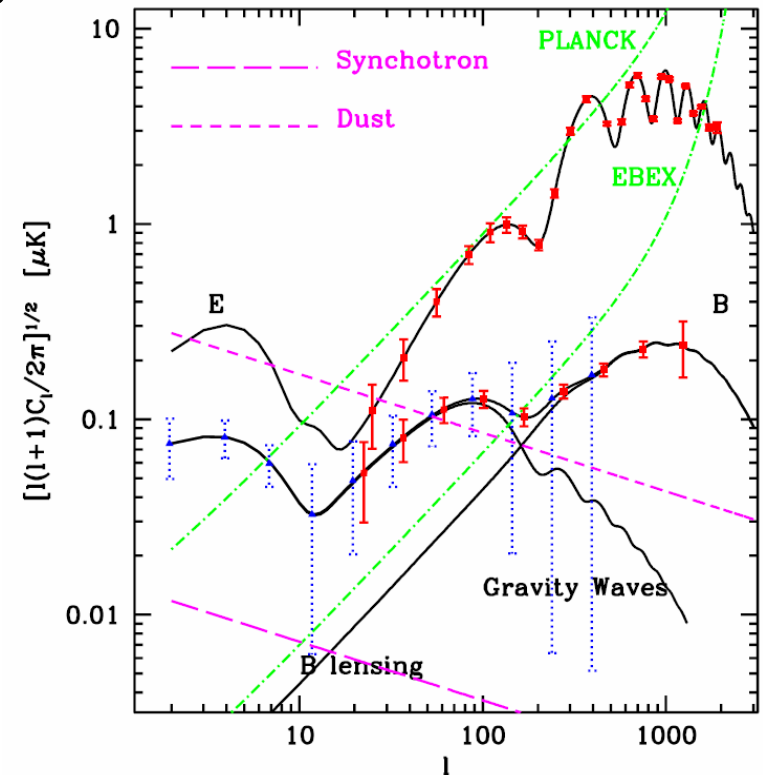
*APC-Paris, Brown University, Cardiff University, Columbia University,  
Harvard University, Lawrence Berkeley National Lab,  
McGill University, SISSA-Trieste, University of California/Berkeley,  
University of Minnesota/Twin Cities, Weizmann Institute of Science*

## • Science Goals

- Detect or set upper bound on inflationary gravity waves:  $T/S < 0.02$  (95%)
- Detect lensing B-mode signal
- Determine properties of polarized dust
- Improve accuracy of cosmological parameters
- Test-bed for satellite technologies

## • Experimental Approach

- 1476 bolometric TES
- 3 Frequency bands: 150, 250, 420 GHz
- Resolution: 8' at all frequencies
- Polarimetry with half wave plate
- Rely on well-developed MAXIMA/BOOM/BLAST balloon technologies and heritage



## • Ballooning

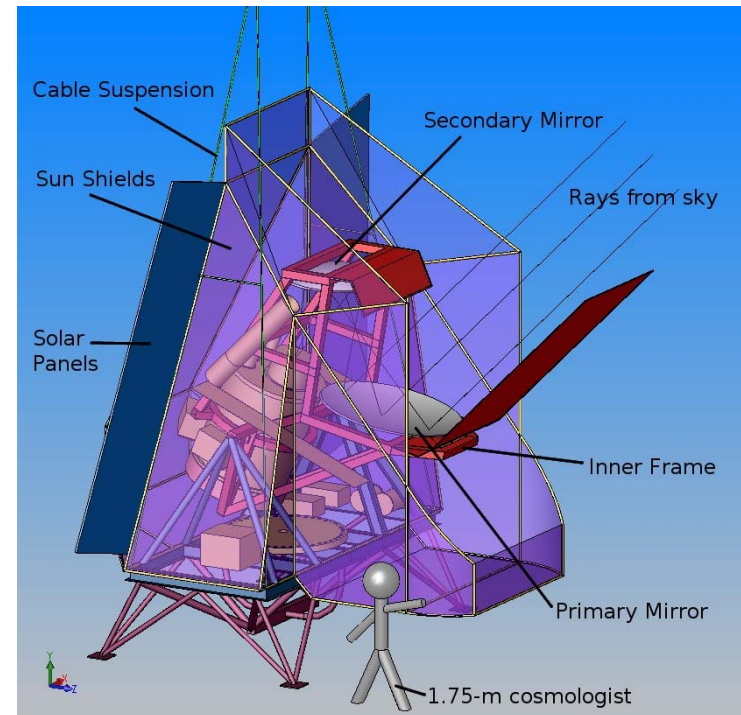
- Minimum 14 day integration on 350 deg<sup>2</sup>  $\implies$  Antarctic LDB
- ~1.2 kWatt
- **6000** Lb science payload, 8000 Lb total suspended
- Altitude: higher than ~100,000 ft.

## • Would like to see

- 30 days (ULDB)
- Cheap, 20% efficiency solar panels
- Higher TM bandwidth

## • Schedule

- NA test flight 2008
- LDB 2009/2010



# Conclusions

- Balloons essential to future CMB
- Enormous science potential
- Need mid-latitude (night) flights with > 1.5 ton to > 60kft for > 25 days
- ULDB? Commercial airship (Sanswire)?